A LITERATURE SURVEY ON SOIL STABILIZATION LIME - FLYASH ADMIXTURES

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by

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Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

A LITERATURE SURVEY ON SOIL STABILIZATION

WITH LIME-FLYASH ADMIXTURES

TO: K. B. Woods, Director
Joint Highway Research Project

February 21, 1957

FROM: Harold L. Michael, Assistant Director

File: 6-19

Attached is a report entitled "A Literature Survey on Soil Stabilization with Lime-Flyash Admixtures" by F. Kocataskin, a member of our staff. The report contains a short summary of selected references on lime-flyash admixtures.

This report was prepared under a contract with the Indianapolis Power and Light Company and is presented to the Board for information.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
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HLM:hgb

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INFORMATIONAL REPORT

A LITERATURE SURVEY ON SOIL STABILIZATION WITH LIME-FLYASH ADMIXTURES

by

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Joint Highway Research Project
File: 6-19

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1. AUTHOR INDEX

Chu, T. H.	(6), (9), (11)
Corson, W. H.	(1), (13)
Davidson, D. T.	(6), (9), (10), (11), (13)
Goecker, W. L.	(6), (9)
Handy, R. L.	(11), (13)
Hoover, J. M.	(10)
Laguros, J. G.	(11)
Mainfort, R. C.	(2)
Meyers, W. F.	(5)
Miller, R. H.	(1), (3)
Minnick, L. J.	(1), (3), (5), (12), (13)
Moh, Z. C.	(6), (9)
Slate, F. O.	(7)
Whitehurst, E. A.	(4)
Williams, R.	(12)
Winterkorn, H. F.	(8)
Yalcin, A. S.	(7)
Yoder, E. J.	(4)

2. SUBJECT INDEX

Soils and Stabilization, General . . . . (8)

Chemical Stabilization, General . . . . (2), (7), (10)

Lime Stabilization, General . . . . (4), (11)

Lime-Flyash Stabilization, General . . . . (1), (5), (6), (9), (10)

Lime-Flyash, Effect of $CaCl_2$ Addition . . . . (1), (9)

Lime-Flyash, Effect of Lime Quality . . . . (11)

Lime-Flyash, Effect of Soil Quality . . . . (3)

Lime-Flyash, Change in Soil Properties . . . . (3), (9)

Test Methods

- Optimum Proportions . . . . (1), (3), (6), (9)
- Preparation of Mixture and Molding . . . . (6)
- Curing Conditions . . . . (4), (6), (11), (13)
- Absorption . . . . (10)
- Plasticity Indices and Shrinkage Limit . . . . . . (3), (11)
- Moisture Density Relationship . . . . (2), (9)
- Compressive Strength . . . . (1), (2), (3), (5), (6), (10), (12)
- Immersed Strength . . . . (6), (10)
- Pozzolanic Strength . . . . (12)
- California or Triaxial Bearing Tests . . . . (11), (12)
- Laboratory Weathering Tests . . . . (1), (2), (3), (5), (9), (12), (13)
- Field Weathering Tests . . . . (2), (3)
- Dynamic Tests . . . . (3), (6), (5), (12)

3. LITERATURE

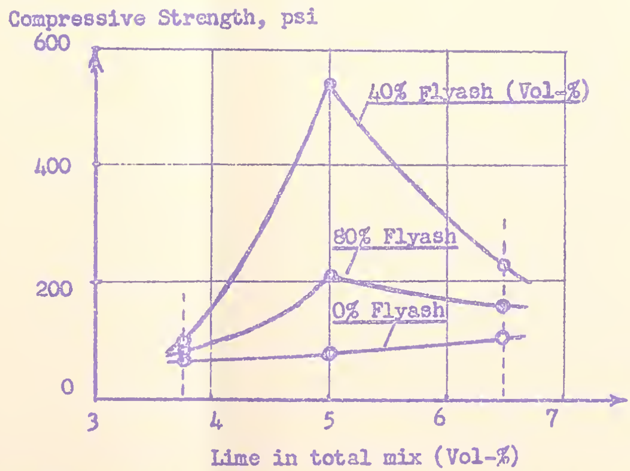
1950

(1) Minnick, L. J., Carson, W. H., Miller, R. M.

Lime-Flyash Compositions for Use in Highway Construction

Proc. HRB Vol. 30 (1950) p. 489

Some years ago Havelin and Kahn, Philadelphia Electric Company engineers, made the discovery that when small amounts of hydrated lime are added to flyash in the presence of water and aggregates, such as sand, in carefully controlled amounts, a product is produced showing the property of high compressive strength when aged for a period of 28 days or longer. Typical data representing results of this study are shown in Figure below. It is noted that a critical range of compositions exist where high strengths



are obtained and the use of either smaller or greater amounts of lime or flyash results in lower compressive strengths.

This discovery was adapted to the field of base course construction of roads in the present study. The tests showed that small amounts of lime with flyash develop considerable strength when mixed with aggregates such as sandy soil, slag, and crushed stone. Good resistance to wetting and drying and freezing and thawing is also evident. Resistance to freezing and thawing is greater in specimens which have cured for longer periods. The use of calcium chloride increases the early strength.

1951

(2) Mainfort, R. C.

A Summary Report on Soil Stabilization by the Use of Chemical Admixtures. U. S. Department of Commerce, Civil Aeronautics Administration, Technical Report No. 136, 1951, Technical Development and Evaluation Center, Indianapolis.

Stabilizing effect may be obtained by bonding, waterproofing or otherwise modifying the natural soil in such a manner that the resulting mixture will withstand detrimental forces of weather, moisture and traffic. This report presents the results obtained from laboratory and field investigations with such materials. It concludes that no entirely satisfactory soil stabilizing agent was found. Several materials were effective under specific conditions or with certain soils. A more basic understanding of fundamental soil properties, composition of natural soils, and their consequent reactivity to chemical modification remains necessary.

Among tests used are: compressive strength, moisture-density relationship, laboratory weathering tests, and field weathering test.

Among agents used are: cement, lime, slag, bituminous materials, resins, (waterproofing and/or bonding) salts, and miscellaneous materials.

1952

(3) Minnick, L. J., Miller, R. M.

Lime-Flyash-Soil Compositions in Highways, Proceedings HRB, Vol. 31 (1952), p. 511

A continuation and extension of the previous study. Optimum proportions for fine-grained, as well as coarse-grained soils are investigated by using compressive strength, transverse fundamental frequency, pulse-group velocity tests and by field performance. The study has shown that improvement is developed in two ways: 1. An immediate beneficial change is brought about in the engineering properties of the soil as evidenced by a marked reduction in plasticity index and an improvement in shrinkage and drainage characteristics. 2. Due to the cementing effects caused by the pozzolanic reaction, the compositions upon aging develop relatively high compressive strength and good resistance to freezing and thawing and wetting and drying.

The determination of the optimum quantity of lime and flyash with fine grained soils cannot be made by using a maximum-density criterion but may be obtained from all of the tests taken together. Both the hydrated lime and flyash require specific concentration ranges for the best results. In general, the finer grained soils require high lime and lower flyash content than coarser grained soils.

(4) Whitehurst, E. A., Yoder, E. J.

Durability Tests on Lime-Stabilized Soils

Proceedings, HRB Vol. 31 (1952), p. 529.

Studies of soil stabilization with lime as the stabilizing agent have been conducted at Purdue University. Results of this investigation include:

(1) Two percent lime is insufficient to affect appreciably the performance of the soils tested;

(2) Five percent lime, or more significantly increased both strength and durability of these soils;

(3) Increased length of curing before testing was, in general, beneficial;

(4) Of the soils tested, the greatest benefits of adding lime were derived by the gravel and the least by the drift soil;

(5) The dynamic test employed seems to be quite adequate as a measure of progressive deterioration and merits further consideration.

<u>1953</u>

(5) Minnick, L. J., Meyers, W. F.
Properties of Lime-Flyash-Soil Compositions Employed in Road Construction, <u>Bulletin 69, HRB</u>, 1953, p. 1.

An evaluation of field projects in which lime and flyash are used for the stabilization of several types of soil indicates that the resulting compositions are very satisfactory as road bases. The evaluation includes laboratory tests for unconfined compressive strength, wetting and drying, freezing and thawing, and pulse group velocity.

<u>1955</u>

(6) Chu, T. H., Davidson, D. T., Goecker, W. L., Moh, Z. C.
Soil Stabilization with Lime-Flyash Mixtures: Preliminary Studies with Silty and Clayey Soils., <u>Bulletin 108 HRB</u> (1955), p. 102.

Various organic and inorganic materials have been investigated as stabilizing agents in the construction of subbase, base, or surface courses. Mixtures of lime and flyash are among those that have shown promise. This paper presents results of laboratory studies of lime-flyash stabilization of silty and clayey soils. The main objectives of the studies were to (1) develop a test method for the preliminary evaluation of lime-flyash-stabilized silty and clayey soils and (2) make a preliminary evaluation of the merits of lime-flyash stabilization in the soils sampled.

The studies have been concerned with: (1) amount of lime and flyash to be added, (2) ratio of lime to flyash, (3) moisture content during mixing and compaction, (4) length of curing, and (5) curing conditions. One of the first things needed for conducting the preliminary evaluation studies of lime-and-flyash-stabilized silty and clayey soils was a simple method of test to provide data for determining benefits to the stability of the soils processed and for selecting the more promising combinations of lime, flyash, and soil for further studies. Other features desired in the test were: (1) use of small test specimens molded to near standard Proctor density, (2) use of curing conditions similar to those obtainable in the field, (3) testing of specimens after immersion in water, and (4) attainment of a fairly high degree of reproducibility of test results. The methods of test presented in Appendix B are recommended for the preliminary evaluation of lime-flyash-stabilized silty and clayey soils.

APPENDIX B

Recommended Test Method for the Preliminary Evaluation of lime-and-Flyash-Stabilized Silty and Clayey Soils

<u>Apparatus:</u> (1) Mechanical Mixer

(2) Compaction Apparatus

(3) Moist Cabinet ($70 \pm 3^{\circ}F$ and 90% RH)

(4) 5000 lb. capacity Testing Machine, rate 0.1 inch/min.

(5) Balance, No. 10 sieve.

<u>Soil:</u> Air-dried, pulverized, screened through a No. 10 sieve.

<u>Mixture:</u> Dry mixing of soil, hydrated lime and flyash and adding of distilled water.

<u>Molding:</u> Immediately after mixing, specimens 2" high and 2" in diameter, 3 or more specimens, compacted, density determined by weighing and by measuring their height.

<u>Curing:</u> In moist cabinet for 7 or 28 days.

<u>Testing:</u> For unconfined compressive strength after 24 hours of immersion.

(7) Slate, F. O., Yalcin, A. S.
Stabilization of Bank-Run Gravel by Calcium Chloride, <u>Bulletin 98</u>, <u>HRB</u>, (1955), p. 21.

Stabilization of a bank-run gravel with calcium chloride was studied and the effects of calcium chloride on the clay and colloridal fractions of the gravel were determined. Among results of importance were:

1. The addition of an optimum (0.5%) amount of calcium chloride resulted in either a slightly higher optimum density or an equal density at a lower compactive effect.

2. Base exchange occurred upon addition of calcium chloride, as shown by a drop in pH. The reaction was complete in one hour. A greater base exchange occurred in the sample with more fines, which correlated with the greater density of this material.

3. Calcium Chloride was effective for increasing density, only on gravel containing an appreciable amount of material passing No. 200 sieve ($> 5\%$).

Theoretical Aspects of $CaCl_2$ Stabilization

Control of the surface phenomena of clays can control soil plasticity and help to stabilize the soil material. Most clay particles have potentially acidic properties, they are negatively charged and have a tendency to migrate towards positively charged units. The neutralization of the surface can be attained by introducing enough positive ions, a salt like $CaCl_2$ for instance. By addition of an optimum amount of $CaCl_2$, the critical point may be attained where positive charge equals negative charge, the distance between particles becomes minimum and results in a more densely-packed condition with maximum density and maximum bearing capacity of the soil.

(8) Winterkorn, H. F.

The Science of Soil Stabilization, Bulletin 108, HRB (1955), p. 1. Soil is a polidisperse system composed of (1) solid inorganic and organic particles, (2) an aqueous phase carrying matter in solution (and sometimes in dispersion), and (3) a gaseous phase of varying composition. The aqueous and the gaseous phases are usually considered together as pore space or porosity.

Characteristics of the Solid Phase

Soils may contain particles ranging from atomic size (10^{-8}cm) to gravel and stone size:

	Designation	Diameter in mm.
Granular	Stones	>20
	Gravel	20-2
	Coarse Sand	2-0.2
	Fine Sand	02-0.02
Silt-Clay	Silt	0.02-0.002
	Clay	<0.002

Designation	Percentage of Silt-Clay
Granular soils	0-20
Cohesive-granular soils	20-35
Cohesive-non granular soils	35-100

In a compacted state, granular soils contain a granular skeleton giving them good volume stability and friction properties, while the silt-clay materials show volume changes with changing moisture content and have low-angles of internal friction.

Considering the great variability of the chemical composition of the parent materials from which soils are formed, an equally great variability in soil composition may be expected. Fortunately, the active soil-genetic factors reduce this variability due to an analytical separation. This separation brings about: (1) breakdown of complicated minerals into simpler compounds, (2) complete or partial removal of soluble products or their concentration in specific layers of the soil profile, and (3) dislocation of colloridal and clay-sized particles and their concentration in specific layers of the soil profile. Therefore it is possible to draw conclusions to soil chemical composition from determination of the granulometry of a soil. Sand (2-0.02mm) is predominantly quartzic and silicic in humid climates but may be any kind of mineral in dry climates. Silt (0.02-0.002 mm) particles resemble quite closely the composition of the parent rock with feldspar, muscovite and quartz usually well represented. Chemical composition of the clay fraction (0.002mm) is well known. Many physical properties of clay systems can be related to the ratio SiO_2/R_2O_3. In Kaolenite this ratio is 2, in laterite soil it falls below 2, in other soils it is above 2.

Characteristics of the Liquid Phase

The chemical formula for water is H_2O. The H_2O molecules, because of their electric structure are associated as well as dissociated as a function of temperature. The large adsorption forces exerted on water molecules by the surfaces of solid soil particles act similar to externally applied pressures. All physical properties of cohesive soils are connected with the behavior of the water substance in strong pressure such as exists on the surfaces of soil particles. Water in soil is never pure but holds materials in solution and dispersion. Disolved materials are mainly salts and acids. In saline soils the solutions may actually be saturated with different salts. In humid climates the solute concentration is relatively low. The water layers next to the solid particles are under high adsorption pressures, which may be higher than 25000 kg/cm^2. The water may be in a solid condition at temperatures above 50°C. The adsorption forces decrease exponentially to about 50 kg/cm^2 at the hygroscopic moisture content, and to zero at the water content at which the solid-water system behaves essentially as a liquid (liquid limit).

The hygroscopicity of a soil increases with increasing clay content and with increasing SiO_2/R_2O_3 ratio of the clay. At the interphase between the surface of the solid soil components and the water film, an electric potential is established, which gives rise to electrokinetic phenomena in soils. The magnitude of this potential and the thickness of the interphase or electric double layer is a function of the surface chemical composition of the solid, of the amount of water present, and the type and amount of ions carried in solution.

The water content at which a soil passes from an essentially solid to a plastic condition is called the plastic limit. These limits, like the hygroscopic water content, increase with increasing clay content and with increasing SiO_2/R_2O_3 ratio of the clay and are, in addition, functions of the type and amount of exchange ions on the clay and of the ions in the aqueous phase.

Properties of Soil-Air

Soil-air is in constant exchange with the atmosphere and its composition reflects that of the atmosphere except for the concentration of those components that are used up or produced by microbiological activity in the soil. Such substances are mainly oxygen, which is used up, and carbon dioxide, which is produced.

The Soil in Situ

Soils are creations of climatic forces, which derive from daily and seasonal temperature variations, from fluctuations in moisture content, from the annual swell and sink of the biologic potential, and from any other periodic phenomenon that affects the surface layer of the earth. As a result, soils in situ are not mixtures of their components, but are naturally organized systems. These systems continue to be exposed to the forces that formed them and their properties are in a continuous state of flux. As a result, soils in situ share many essential properties with living systems and may almost be considered as living.

The primary particles of a soil are very rarely encountered as independent individual constituents but are cemented together into secondary aggregations and crumbs by means of inorganic or organic binders. The stronger secondary particles even persist in disturbed and molded specimens, which results in relatively large angles of friction of clay soils in the molded wet or in coherent air-dry condition. The aggregation increases the size of the soil pores which results in a greater permeability for water and air than the soil would have in single-grain structure at the same porosity value.

Moisture moves in and out of the soil profile and up and down in the profile as a result meteorological and soil physical factors. As has been seen previously, the dominant direction and pattern of moisture movement determines the climatic soil type encountered.

The following potentials are available for water movement in soils: (1) gravity, (2) hydration energy of ions, (3) osmotic energy, (4) capillary potential, (5) thermo-osmotic potential. Although the order of magnitude of these potentials can be approximately calculated from theoretical considerations and with the help of experimental data, little is known concerning the resistance to flow under these potentials because flow is primarily of a film and not of a capillary character.

Mechanical Resistance of Soil Systems

For granular soils the shear resistance is expressed as $S = \sigma'_n \cdot tg\Phi$. The coefficient of friction $tg\Phi$ is a function of the voids ratio, of σ'_n and of form factors. It may obey a relationship of the following type:

$$tg\Phi = \frac{k}{V - V_s}$$

with

K = constant

V = bulk volume

V_s = solid volume

Since the resistance properties of granular materials are dependent solely on friction and since the frictional resistance is directly proportional to the normal pressure on the shearing plane, the resistance properties are very low in the surface layers of granular masses where the normal pressure on the shear plane is small. Therefore, such systems require cementation for their stabilization. The particles can be cemented together by any one of the large number of inorganic and organic cements or by combinations of inorganic cements with organic cements or with water proofing agents. Such systems are portland cement concrete, bituminous concrete, clay concrete, waterproofed clay concrete and sand-clay as well as waterproofed sand-clay. The type of cementing substance depends on prevailing climate. Under American conditions, mainly portland cement, flyash-lime combinations, and bituminous materials have been employed. In dryer climates gypsum plasters, sorel and other water susceptible cements can be used successfully. With proper water-proofing the latter are suitable even in moist climates.

Silt clay systems posses great cohesive strength in dry condition but lose the strength in the presence of moisture which they absorb avidly under swelling. There is a dividing line between non-swelling and swelling soils at 35% clay contents. The shear resistance of cohesive soils is usually expressed as

$$S = \sigma \cdot \tan \Phi + C$$

with C as cohesion. Friction tan Φ and cohesion C are both functions of the density, moisture content and of the manner in which the moisture content has been attained. The soil cohesion may be considered as a result of the attraction forces acting from the mineral surfaces through the water films and of geometric factors that have the functions and therefore the properties of an angle of friction. Accordingly, one may write

$$C = \text{Internal pressure} \times \tan \Phi$$

For soils at very low moisture content this internal pressure is theoretically of the order of 10^6 psi. It falls logarithmically to zero at a moisture content at which the soil flows under its own weight.

Soils can be considered as (1) solids if their moisture content is below the shrinkage limit and if they have been dried to this point from higher moisture contents, as (2) being in the plastic state if their moisture content falls between the plastic and liquid limit, and (3) as liquids if their moisture content is above the liquid limit. The location of these limits depends on the clay and colloid content of the soils, on the type and activity of the clay fraction, and on the granulometry of the entire soil including its clay fraction.

Stabilization of Silt-Clay Materials

In the range of granular materials there is a lack of natural binder which must be made good by addition of cementing and waterproofing materials. In the range of granular-cohesive materials with 20-35% of silt and clay, we may have well-graded material that corresponds to the established requirements of granular stabilization. In the stabilization of cohesive soils that do not contain granular skeletons difficulty arises from the fact, that the seat of the resistance providing cohesion is also the seat of water affinity. The simplest method of stabilizing such materials is to (1) deprive the component particles of their water affinity and (2) to cement these together. This exactly is achieved by the oldest method of soil stabilization, namely the burning of clay soils. Another use of this principle is to replace the water attractive inorganic exchangeable cations by means of water repellent organic cations and to cement the soil constituents, that have now lost their water affinity, together by means of an organic cement. This can be done using aniline-furfural and similar resins. Another method is to create strongly water resistant secondary soil aggregates which are then cemented together by means of inorganic binders such as Portland cement, flyash-lime combinations, gypsum plasters, sorel cements, etc. A less-positive but still effective method, if properly used, is to stabilize the moisture content of a soil system by preventing the intake of excess water. This water-proofing may be achieved by bituminous, resins, fats, waxes etc.

<u>1956</u>

(9) Goecker, W. L., Moh, Z. C., Davidson, D. T., Chu, T. Y.
Stabilization of Fine and Coarse-Grained Soils with Lime-Flyash Admixtures
<u>HRB, Bulletin 129, 1956, p. 63</u>.

Laboratory studies of lime-flyash stabilization of eight fine and coarse-grained soils. Results indicate that:

1. Maximum density decreases and optimum moisture content increases with the addition of lime-flyash.
2. Strength increases with mixing, curing time, curing temperature.
3. Optimum ratio of lime to flyash and the amount of lime-flyash additive varies with soil.
4. Small percentage of calcium chloride increases the strength.
5. Addition of lime-flyash improves consistency limits and shrinkage properties.
6. Lime-flyash stabilized soils do not meet present durability criteria for soil cement.
7. A more realistic criteria for freezing-thawing and wetting-drying necessary.

Appendix: Estimation of Optimum Moisture Content of Lime, Flyash, and Soil Mixture. Example:

Three Tests:

	Max Density	Opt. Moisture
Soil alone	108.6 pcf	17.7%
50% Soil and 50% Lime	85.5 "	29.2%
50% Soil and 50% Flyash	106.2 "	17.9%

Variation in optimum moisture for 1% lime $= \frac{11.50}{50} = 0.23\%$ increase

Variation in optimum moisture for 1% flyash $= \frac{0.2}{50} = 0.004\%$ increase

Variation in density for 1% lime $= \frac{23.1}{50} = 0.462\%$ decrease

Variation in density for 1% flyash $= \frac{29}{50} = 0.098\%$ decrease

For a mixture containing a % lime b % flyash:

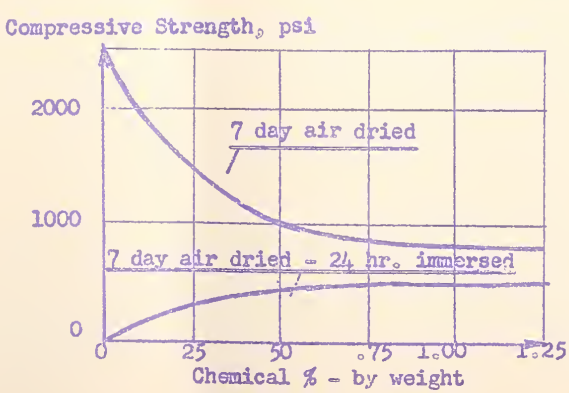
$$O.M. = 17.7 + (0.230 \times a) + (0.009 \times b)$$

$$M.D. = 108.6 - (0.962 \times a) - (0.098 \times b)$$

(10) Hoover, J. M., Davidson, D. T.

Preliminary Evaluation of Some Organic Cationic Chemicals As Stabilizing Agents for Iowa Loess, Iowa Eng. Exp. St. 1956.

Presents results of preliminary evaluation studies of a number of organic cationic chemicals as stabilizing agents for Iowa Loess. Unconfined compression test, moisture absorption, and swelling after 24 hours of immersion are used. Criteria for judging relative stability of the specimens were change in height, absorption, air-dry and immersed compressive strengths. Low volume change and low moisture absorption and improvement in immersed strength are the principal indications of benefits to stability by chemical treatment. Figure demonstrates the influence of admixtures on air-dry and on immersed unconfined strength. The immersed strength data demonstrates the effect of the chemicals as waterproofing agents. Table demonstrates comparison with other kinds of stabilizing agents for specimens cured 7 days in moist cabinet at 70°F temperature.



TABLE

Admixture	Proportion (weight)	Immersed Comp. Strength
None	—	Failed during immersion
Waterproofers	0.08-0.3	260 - 330 lb.
Cutback asphalt	10	220 lb.
Lime-flyash (1:2)	18	485 lb.
Hydrated Lime	6	250 lb.
Portland Cement	15	1780 lb.

Theoretical Aspheets of Soil Waterproofing

Organic cationic chemicals, which dissociate in water to produce organic cations which may have exceedingly complex structures compared with the organic cations such as calcium, magnessium, hydrogen or sodium, are used as soil waterproofers because they are of hydrophobic nature. When incorporated in the soil, in amounts less than the cation exchange capacity, the organic cations are adsorbed completely to the clay surfaces, replacing smaller, inorganic cations present. They may be visualized as being oriented in such a way that the hydrophobic part of the cation is directed outward. Considerable areas are thus formed in clay surfaces that are not wetted by water. The soils water absorption, swelling, plasticity, and shrinkage properties are decreased. Reduction of air-dry strengths is the only undesirable property change noted, but this is more than compensated for by the increase in immersed strength.

(11) Laguros, J. G., Davidson, D. T., Handy, R. L., Chu, T. Y. Evaluation of Lime for Stabilization of Loess, Iowa Eng. Exp. St., 1956, HRB Abstracts Vol. 26 (Dec. 1956) N. 11, p. 94.

In lime stabilization of soils it is recognized that there are wide variations between different soils, and treatments are adjusted accordingly. Recent research shows that some limes are more effective depending on Ca:Mg ratio and on quicklime versus hydrated lime.

On the basis of compressive strength, quicklime appears to be more effective with loess than the equivalent amount of hydrated lime, and dolomitic lime is more effective than calcitic lime: Data are given comparing the CBR, plasticity indices, and shrinkage limits obtained after treatment with hydrated lime and quicklime. A high temperature curing study is also included.

Reaction of Lime With Loess

It is generally recognized that cation exchange is a mechanism whereby lime can improve the properties of certain soils. However, in the loess samples investigated the natural cations are calcium, and the flocculation mechanism does not appear to be so much an ion exchange as a crowding of additional ions on the clay. This would lower the zeta potential (the negative effective charge at the surface of the clay). The addition of positive ions will reduce the charge and produce a flocculation, which is immediately observed during mixing and is reflected in lowering of the liquid limit, raising of the plastic and shrinkage limits, and lowering of the maximum compacted density. In addition to the immediate improvement in properties brought about by flocculation, there is a long-term strength gain, which is sensitive to temperature and suggests a chemical reaction. Test results indicate that this reaction is not the carbonation, not a reaction between lime and clay, but it is a pozzolanic reaction between lime and the non-clay minerals, especially with quartz so long as the particle size is fine enough.

(12) Minnick, L. J., Williams, R.

Field Evaluation of Lime-Flyash-Soil Composition for Roads

HRB, Bulletin 129 (1956), p. 83.

Recommended Laboratory Evaluation

Adequate evaluation should involve at least the following parameters:

1. Lime-flyash-soil pozzolanic strength test. A minimum requirement of 500 psi (unconfined) is required using a 7 day moist cure at 140°F and testing in oven dry state.
2. Lime-flyash-soil bearing test (conventional bearing or triaxial) at optimum moisture, maximum density and cured under tree cycles of wetting and drying at room temperature, at the age of 7 to 28 days.
3. Freezing and thawing test involving procedures similar to that present in the job site. Freezing and thawing from the upper surface downward for a minimum of five cycles.
4. Where equipment available, sonic tests are helpful.

The above recommendations should give the engineer confidence in the acceptability of the composition for any project.

(13) a) Soil Stabilization with Lime-Flyash Mixtures

Special Discussion

HRB, Bulletin 129 (1956), p. 100

Minnick, L. J., Corson, W. H.

Curing: It is of definite benefit to include conditions of alternate wetting and drying cycles or even high-low humidity cycles.

The recrystallization of soluble lime hydrates, as well as the outogeneous healing which is a function of the bicarbonate reaction have important bearing.

A rapid laboratory test which endeavors to simulate long-term effects is the high-temperature curing, 5 to 14 days at 140°F are equal to 6 months to 7 year at 70°F.

(13) b) Davidson, D. T., Handy, R. L.

More recent research at the Iowa Engr. Exp. St.

1. Alternate wetting and drying in some cases benefits strength gain more than ordinary curing. Reason not definitely known.
2. Recrystallization of lime adds to strength.
3. Sealing the specimens against carbonation has found to increase long-term strengths.
4. High-temperature curing may occasionally give erroneous results (mineralogical composition of soil).